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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

HOW ARTIFICIAL SATELLITES
RETURN TO EARTH

by

HUA Pao

FOREIGN TECHNOLOGY DIVISION

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HOW ARTIFICIAL SATELLITES RETURN TO EARTH

HUA Pao

CHAIRMAN MAO PERSONALLY STARTED AND LED THE GREAT PROLETARIAN CULTURAL REVOLUTION AND THE CRITICIZING LING AND CONFUCIUS MOVEMENT WHICH HAD THOROUGHLY CRITICIZED THE REVISIONISM LINE OF LIU SHAO CHI AND LING PIAO AND PROMOTED A LUXURI[illegible] [illegible]VELOPMENT OF OUR SCIENCE AND TECHNOLOGY. ON 26 NOVEMBER 1975, [illegible] ARTIFICIAL EARTH SATELLITE LAUNCHED BY OUR COUNTRY RETURNED TO THE GROUND ACCORDING TO SCHEDULE AFTER A NORMAL PERFORMANCE. THIS WAS A NEW ACCOMPLISHMENT IN THE DOMAIN OF SCIENCE AND TECHNOLOGY. IT SYMBOLIZED THAT SPACE TECHNOLOGY HAD MARCHED INTO A NEW STAGE WHICH WAS A POWERFUL COUNTERATTACK ON THE AGITATION DUE TO THE REVERSAL OF DECISIONS BY THE RIGHT DEVIATIONISTS.

THE RETURNING OF THE SATELLITE AND SPACECRAFT TO EARTH IS AN IMPORTANT AND COMPLICATED PROBLEM IN SPACE TECHNOLOGY. IN ORDER THAT READERS GET SOME UNDERSTANDING IN THIS PROBLEM, THIS ARTICLE IS SIMPLY AN INTRODUCTION TO THE BASIC KNOWLEDGE OF THE RETURN OF THE SATELLITE TO EARTH.

Spacecraft, including artificial satellites, space ships and different space vehicles, are divided into two categories depending upon whether or not they are required to return after accomplishing their predetermined flying mission. The two categories are "non-returnable" and "returnable". Communication satellites, astronomy satellites, and weather satellites which rotate around the Earth in orbit year after year and need not return to Earth belong to the former; manned spacecraft and some scientific satellites which leave orbit after accomplishing their mission and return to Earth with a certain safety speed to land at a predetermined area belong to the latter.

The so called returnable satellite does not mean that the entire satellite returns to Earth. In order to reduce the weight of heat protection and the parachute landing system, that is to reduce the weight of the entire satellite, the necessary returnable items and the facilities that have to work during the returning process are purposely put together in a capsule which is called the reentry capsule (Fig. 1), and items which need not be returned to Earth, such as the facility cabin and orbiting module, are put in another capsule during design. Before the satellite returns to Earth, it discards the module that need not be returned, and only the reentry capsule (it will be called satellite later) proceeds with a series of technical procedures and returns to Earth.

In our daily life, when anything such as a stone falls from a high altitude, we feel that the further it falls, the faster it falls. But why will a satellite fall slower the further it falls?

This is because the satellite has a high initial velocity. When an object moves in air, the resistance acting on the object is proportional to the air density ρ, the cross-section of the object S, and the square of the velocity V; it can be expressed as following:

$$D = \frac{1}{2} \rho V^2 C_D S,$$

in which C_D is a ratio related to the shape of the body and is generally called the drag coefficient. The satellite enters the atmospheric shell with a very high velocity (several kilometers per second). When designing a satellite reentry capsule, an appropriate aerodynamic configuration is chosen to have a higher drag coefficient. Thus, the air drag acting on the satellite is very strong; it reaches from several times even to dozens of times of its own weight. The satellite then reduces its speed with a deceleration of several times to more than ten times the gravitational acceleration. In daily life, the descending velocity of an object is much smaller than that of the satellite, but the drag is smaller than the weight; therefore the further it falls the faster it goes.

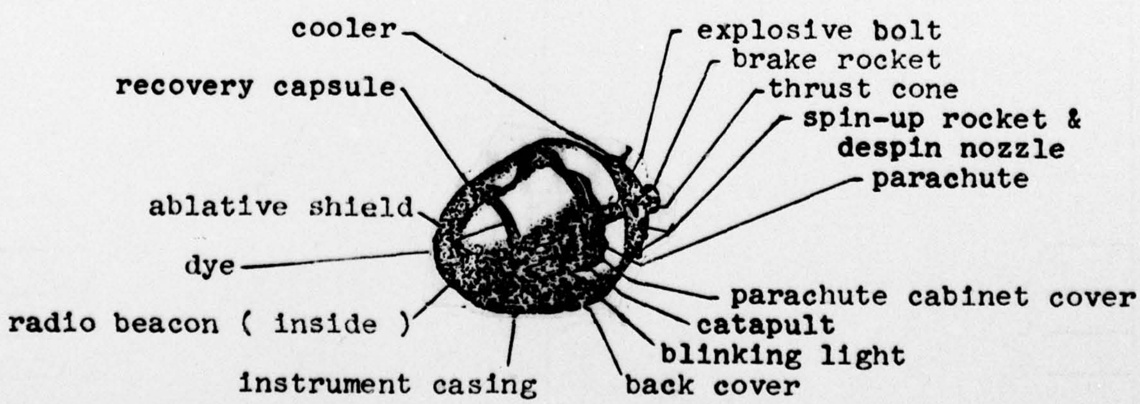

Fig. 1 An earliest model of the reentry capsule of a satellite.

The launching of an artificial satellite is a process of acceleration. It is carried by a carrier rocket from a state of rest and accelerates gradually to orbital velocity (near-earth orbit is about 8 km/s). The reentry of a satellite is a deceleration process; it is gradually reduced from orbital velocity to a velocity of a dozen meters per second or a still lower velocity at several meters per second, and then to a safe landing or splash down.

Theoretically speaking, for the return of a satellite, a rocket could be fired in a direction opposite to that for launching to reduce the speed. The procedure is a reverse of the launching process along the launching orbit. But it requires a fairly large power plant and large amount of propellent which is the payload of the carrier rocket during launching, thus greatly increasing the flight weight of the launched satellite; therefore, this method is not economical nor practical. It is not being used in practice.

The practical method is to use a retrorocket with some energy to act in a short period of time so that the satellite reentry capsule will leave its original orbit and change its direction to the atmospheric orbit; then it does not use rocket power to reduce the speed, but uses the air drag itself in the atmosphere and the drag caused by the parachute before landing to further reduce the speed of the satellite.

According to such factors during the reentry of the returnable satellite as the condition of movement in the atmosphere, whether the aerodynamic configuration is variable, etc., the returnable satellites are divided into two categories, the ballistic reentry

and the aircraft-type reentry. The simplest kind of ballistic reentry vehicle is used as an example to illustrate the reentry process, as follows.

LEAVING ORBIT

The first step in the reentry of a satellite is to leave its original orbit and change to another new orbit to be able to enter the parking orbit of the atmospheric shell.

Assume that the speed of the satellite at some point A on the orbit is V_1. The satellite is pushed by a retrorocket for a short duration along a direction which makes an angle η with the horizontal surface. In the direction of angle η the satellite gains a small increment of velocity ΔV (several meters per second), and then flies with a new velocity V_2 (Fig. 2). In comparison with the original velocity V_1, not has only the magnitude of the velocity V_2 changed some, but the direction has also drifted toward Earth with a small angle (only a few degrees). Thus, the satellite changes to a new elliptical parking orbit. Of course, this new orbit must intersect with the atmospheric shell. Otherwise, the satellite will continue to orbit the Earth along the new orbit.

After the satellite leaves the original orbit, it falls freely along the parking orbit under the force of gravity and enters the atmospheric shell at an altitude of about 100 km. The angle between the direction at which the satellite enters the atmosphere and the horizontal surface is called the reentry angle φ. If the reentry angle is too small, the satellite only touches the atmospheric shell and passes by, and is unable to enter the atmospher;

if the angle is too large, the deceleration (called braking acceleration) is too high due to the air drag when the satellite moves in the atmosphere or the aerodynamic heating is too intense; thus, the structure has to be more complicated and the weight has to be increased.

Therefore, when designing an orbit, proper orbital parameters such as angle of inclination, period, etc., should be chosen so that the recovery orbit will pass through the space of the predetermined recovery area. During the return of the satellite, the position for firing the retrorocket must also be chosen properly so that the reentry capsule will fall to the predetermined recovery area.

There is no device in the equipment module of the satellite to adjust the attitude of the satellite. Before returning, first the direction of the central axis of the satellite (that is, the direction of the thrust of the retrorocket) is adjusted to the direction required to fire the retrorocket,then the equipment module is separated from the reentry capsule,and then the retrorocket is fired.

If there is no attitude control device in the reentry capsule, it is necessary to make certain that the reentry capsule rotates about its own central axis at about 1-2 revolutions per second before firing the retrorocket in order to compensate the drift caused by the thrust of the retrorocket and the eccentricity of the gravity of the reentry capsule. This is called spin stabilization. After the retrorocket has completed its work, the rotation of the reentry capsule must be reduced to not more than 10 revolutions

per minute. Whether the attitude control device can accurately adjust the attitude of the satellite to the required direction at which the retrorocket starts to work is one of the key problem for the satellite to return normally.

REENTRY INTO THE ATMOSPHERE

When a satellite returns from orbit, it possesses a lot of energy including dynamic energy (due to the velocity of the satellite) and potential energy (due to the altitude of the satellite above the Earth). After it enters the atmosphere, the satellite reduces its speed rapidly due to the air drag. During the process of reducing the speed, the major part of the large amount of energy of the satellite is transformed into heat energy; thus its temperature rises very rapidly. Therefore, the aerodynamic heating and heat protection are the main problems of satellite reentry.

Assume that the velocity of the satellite at reentry is $V = 7.73$ km/s; then the dynamic energy possessed by every kilogram of weight is $E = \frac{1}{2} mV^2 = 2.99 \times 10^7$ joules = 8.34 kilowatt hours. Such a large amount of heat could heat 30 kg of steel to 2,000°C. This means that if all the energy possessed by a satellite at the beginning of its reentry is converted to heat and all the heat is contained in the satellite itself, the heat will burn the entire satellite including the heat protection and cooling system to ashes. However a large portion of the heat converted from the energy possessed by the satellite is dissipated into space due to the influence of the shock wave and radiation, and only a small amount of heat is transmitted to the structure of the satellite.

The heat dissipation of the shock wave is the result of the interaction of the air molecules around the satellite. The velocity of the satellite is very high after it enters the atmosphere (the velocity at an altitude of 40 - 50 km is about 10 - 20 times of the velocity of sound), and the satellite constantly and forcefully compresses the air in front of it. The density of the compressed air increases by more than 10 times, the temperature increases to about 6,000 - 8,000°C, and a strong shock wave is formed in front of the satellite. The air molecules hit the surface of the satellite and bounce off. Many of the bounced air molecules impinge on the new incoming air molecules, thus preventing them from making contact with the surface of the satellite but scattering them into the air stream. Consequently, a large amount of heat is dumped in the space between the shock wave and the surface of the satellite. The shock wave extends outward and backward for a long way from the satellite and forms a big trail. This trail is formed of heated air which includes the largest portion of the heat generated by the reentry satellite when it reenters the atmosphere. The heat of the trail dissipates to the surrounding air. The dissipated heat is proportional to the strength of the shock wave. The stronger the shock wave, the more the dissipated heat, and the less the heat is transmitted to the satellite. Therefore, the reentry capsule of a satellite chooses a blunt aerodynamic head, unlike the supersonic airplane which chooses the long streamline. A suitably chosen aerodynamic contour could dissipate 98% of the heat generated from the reentry of the satellite into the atmosphere,

and only about 2% of the heat is transmitted to the shell of the satellite.

The contour of the reentry capsule of a satellite is generally very simple; it is usually an axisymmetrical rotator, such as the shape of a ball, or the shape of a cone is added to a hemisphere (Fig. 1), etc.

Though only a small portion of heat is transmitted to the satellite, it is still quite serious: the peak value of the heat stream at the nose could be several hundred kilocalories per second per square meter and the total heat on each square meter could reach several tens of thousands of kilocalories. Therefore, the satellite must take reliable heat protection measures; otherwise it will burn up in the atmosphere like meteorites.

During reentry, each portion of the satellite uses a different heat protection method according to the intensity of aerodynamic heating. There are three commonly used heat protection methods:

1. Heat Sink Method: The shield of the heat protection structure for heat sink method is rather thick. It uses good heat conductivity, high specific heat ratio, and high-melting metals such as beryllium, copper, etc. Thus, the shield has a larger heat capacity. The aerodynamic heat is absorbed by the shield when transmitted to the structure and stored in the shield. The heat protection ability of the heat sink method is limited; it is only used at the portion with very little heat on it.

2. Radiation Method: The shield of a radiation-type heat protection structure uses a very thin high-temperature alloy by which

the heat is radiated to air. Under the influence of the heat stream, the temperature of the shield increases continuously, and the heat radiated from the surface of the shield increases according to the temperature of the shield. When the temperature is raised to a certain degree, the heat stream transmitted from the air stream to the shield is equal to the heat stream radiated from the shield surface and the shield temperature will not raise any further. This temperature is called equilibrium temperature. Radiation type heat protection is suitable under the condition of small heat stream.

3. Ablation method: The ablation type heat protection method is to let the surface of the material burn, that is, it lets the solid material melt, vaporize, sublimate, or decompose under the strong heat conditions to carry away the heat and save the main structure.

There are many kinds of ablative material. The carbonized ablative material is the main one, such as glass cloth reinforced phenolplast and nylon reinforced phenolplast (the so-called glass steel). Under the influence of heat flow, the temperature of the structural surface rises to the decomposing temperature and the polymer of glass steel (such as phenolic resin) starts to decompose to gas and carbon residue. During this process tremendous heat is absorbed. Gradually the decomposed area extends inwardly due to the continuous heat. The decomposed gas gradually escapes to the surface of the structure, dissipates into the air flow, increases the thickness of the boundary layer of the air flow, and forms a

gas protection layer which prevents the heat flow to the satellite to a certain degree. At the same time, due to the exhaust of gas a carbonized layer is formed on top of the decomposed area. The carbonized area is a perforated structure which is good air insulation. The rise of temperature on the surface of the structure radiates a portion of the heat also. The ablative heat protection is an effective and reliable heat protection method.

LANDING

After the satellite enters the atmosphere, its speed is reduced very rapidly due to the air drag. When it descends to an altitude of about 15 km, the speed is gradually reduced to subsonic. At this moment, if the speed is not further reduced, the satellite will crash on the ground with a velocity of more than 100 m/s. In order to assure the vehicle's landing at a certain safe speed, it is necessary to further reduce the speed before landing. At present, the returnable satellite use parachutes as a means of reducing landing speed (Fig. 3).

The area of the parachute is inversely proportional to the square of the equilibrium descent velocity. If the landing speed is made too low, the area of the parachute must be very large. Generally the landing velocity can have a maximum of 15 m/s according to the equipment on the satellite.

The parachute system starts to function at an altitude of 15 km or lower. Though the speed of the satellite is only about 200 m/s, it is still too high for the parachute. Usually there are

two stages in reducing the speed, first, a small parachute opens at an altitude of 15 to 7 km to reduce the speed of the satellite to about 60 - 80 m/s; then the main parachute opens at an altitude of 7 to 3 km to ensure the satellite's safe landing.

The ballistic or semi-ballistic type reentry vehicle has no or limited mechanical flying capability; it can land only vertically by parachute. Whether a ballistic satellite can descend to a predetermined area depends upon the attitude of the satellite at the time that the brake rocket starts functioning and the impulse of the brake rocket. When the satellite leaves its original orbit, it follows a trajectory and returns to Earth without any control. Therefore, if there is any deviation at the beginning, there will be a large deviation at the point of descent since there is no way to correct it during the reentry. The semi-ballistic type reentry satellite produce a small lift during the reentry process. The position of the point of descent of the satellite may be adjusted by controlling the direction of the lift.

In order that the satellite be discovered by the ground recovery team on time after landing, the satellite is equipped with location-indicating devices such as a radio beacon, blinking light, smoke bottle, etc., among which the radio beacon is the most important one. It sends signals before and after the landing. From the signal the ground recovery team can locate the point of descent of the satellite.

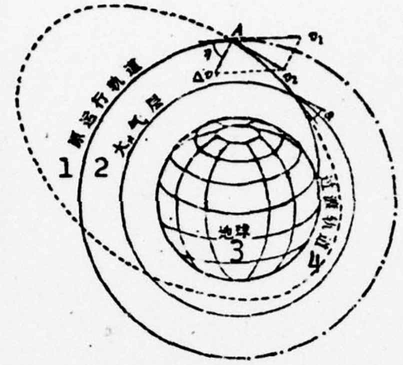

Fig. 2 Diagram of the reentry orbit of satellite (not in proportion).
Key to Fig. 2
1. Original orbit.
2. Atmoshpheric shell.
3. Earth.
4. Interim orbit.

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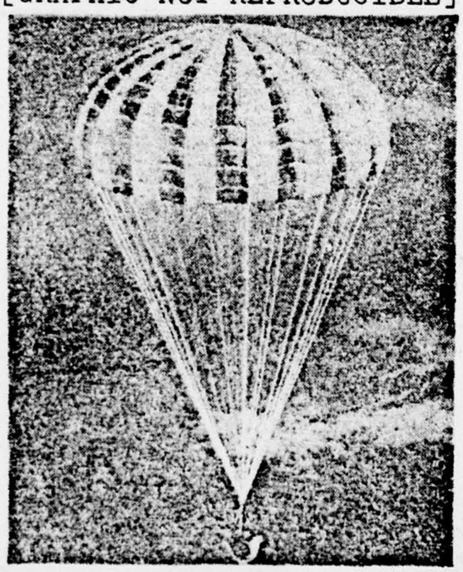

Fig. 3 Animal-carrying satellite descends by means of parachute.

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